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# Does 'Forage-Livestock Balance' policy impact ecological efficiency of grasslands in China?

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ABSTRACT

Grassland has critically important ecological efficiency as well as economic values. While overgrazing and climate change have been reported to lead to the deterioration of grassland ecosystem functions and ecological efficiency, the implementation of a rational policy may mitigate such effects. The 'Forage-Livestock Balance' policy refers to balancing the relationship between forage productivity and grazing capacity of grasslands, and has been implemented in northern grassland areas in China since the year of 2000. In this study, we firstly examined spatio-temporal changes in the ecological efficiency of grass-based livestock husbandry in Hulunbuir, Inner Mongolia, China, using the Super-efficiency Data Envelopment Analysis method, and then analyzed the effects of the 'Forage-Livestock Balance' policy on the ecological efficiency. The Difference-in-Difference (DiD) approach was applied to investigate the differences of ecological efficiency in county-level outcomes between prior to and after the implementation of policy. The results showed that the county-level ecological efficiency in Hulunbuir was low in the year of 2000, thereafter it displayed an increasing trend from year of 2000–2015, though no significant differences were occurred in each of counties of Hulunbuir. Among the counties, Yakeshi county and Zhalantun county had the highest ecological efficiency, and Chen County had the lowest. The DiD analysis suggested that the 'Forage-Livestock Balance' policy had a remarkable effect on the ecological efficiency of grass-based livestock husbandry. Compared to traditional pasture management, the policy has greatly improved the ecological efficiency of grasslands. Our research results provide a useful reference for the sustainable development of grassland livestock management, which is an important countermeasure to improve the efficiency of grassland livestock husbandry, alleviate the pressure on grassland ecosystems, and ensure the living standards of residents in the context of climate change and the risk of recurring disasters.

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## 1. Introduction

Grassland ecosystem plays an important role in global climate change, depending on the balance between the sequestration of CO2 via grassland vegetation and the release of CO2 through the respiration of microbes, animal and plants. If a grassland ecosystem sequesters more CO2 than it emits, it will act as carbon sink, and on the contrary, it is known as carbon source (Schuman et al., 2002). With the gradual formation of the carbon trade market internationally, grassland as an important carbon sink may generate much more economic values than as livestock farming (Björnsson et al., 2016; Smith, 2014). In many developed countries, grassland may produce more values in soil and water conservation or recreation than in grazing and/or forage production. The foreseeable impact of climate change will alter the current balance of grassland ecosystem, and there will be obvious changes to the geographical distribution and species composition of grassland vegetation (Yin et al., 2014; Liebig et al., 2010). Furthermore, in recent years, human activities, combined with climate change, have resulted in severe degradation, desertification, and significant productivity decrease of the grassland (Zhang et al., 2011; Li et al.,

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2012; Chen et al., 2014; Wang et al., 2017a,b), which has led to a decline in the yield of dominant forage species and affected the carbon sink function of grassland ecosystems (Liebig et al., 2010; Wang et al., 2011a). Over-exploitation of ecosystems for food production has been identified as the major human interventions which generated huge pressures and impacts on the environment (Castellani et al., 2017). Similarly, severe damage and fragile habitats have weakened the ability of grassland ecosystem to cope with extreme weathers caused by climate change and to exert significant effects on its carbon sink function, generating increasingly more economic and safety threats to local residents (Reser and Swim, 2011; McCright and Dunlap, 2011). In the next decades, livestock production is unlikely to be reduced as global demand for animal protein is far higher than the current supply (Abbasi and Abbasi, 2016), hence balancing grassland ecological function and livestock production is a global challenge.

Grassland is the area-largest territorial ecosystem in China, and accounts for 41% of the total national land area. The carbon storage of grassland vegetation in China is about 1 peta-grams (Pg) C and grassland soil carbon storage is approximately 28.1 Pg C, totaling about 29.1 Pg C (Fang et al., 2010), playing a significant role in carbon sequestration in China. Yet, primarily located in the North and as the homeland of most ethnic minorities, China's grassland is sensitive to climate change (Deng et al., 2011; Wiesmeier et al., 2015; Wang et al., 2017a,b). Furthermore, grassland provides nearly one third of the national red meat and dairy products, respectively, and it is important for national healthy food supply (Shen et al., 2016). Unfortunately, it is believed that a large proportion of China's grassland has been degraded to various degrees for a number of reasons, including overgrazing, overpopulation, mining, farming activities and climate changes (Tao et al., 2015).

Faced with increasing pressure on climate change and grassland degradation caused by poor management, the Chinese central government has implemented a series of ecological protection and construction projects to restore grassland ecosystems (Ministry of Agriculture, 2007). The recent report of the 19th Congress of the Party emphasized that ecological civilization is the Millennium Development Goal of the country's sustainable development. As an important indicator of ecological civilization, “ecological efficiency” has always been the focus of government and researchers (Deng et al., 2016; Huang et al., 2016). The concept of eco-efficiency is based on the added value and environmental impact of economic activity (Schaltegger and Sturm, 1990), which centralizes economic value by minimizing resource inputs and environmental costs (Kuosmanen and Kortelainen, 2005; Wang et al., 2011b; Beltrán-Esteve et al., 2014). The concept of ecological efficiency is based on the added value and environmental impact of economic activities (Schaltegger and Sturm, 1990), and the central dogma is to maximize the economic value by minimizing resource inputs and environmental costs (Kuosmanen and Kortelainen, 2005; Wang et al., 2011a,b; Beltrán-Esteve et al., 2014). The World Council for Sustainable Development (WBCSD, 1992) defined ecological efficiency as ‘the life cycle environmental impact and resource consumption control within the scope of the bearing capacity of the earth, so as to provide a price competitiveness of products or services, on the basis of guaranteeing the quality of human life and the demand’. The Organization for Economic Co-operation and Development (OECD) extended the concept of ecological efficiency to government, industrial and other social organizations (OECD, 1998; Huppes and Ishikawa, 2005). Recently, ecological efficiency was also regarded as an aspect of sustainability pertaining to the environmental performance of a production system value (Korol et al., 2016).

The current research on ecological efficiency has been mainly focused on the measurement and application of ecological efficiency on grassland management. The ratio method is regarded as the simplest way to measure ecological efficiency (Verfaillie and Bidwell, 2000). However, the single ratio method implies that the optimal solution is achieved. The influences of different environments cannot be distinguished, and a set of optimal solutions cannot be provided to decision-makers, which makes the method more applicable to the analysis of independent non-contact objects (Neto et al., 2009). For more complex situations, the use of indexes and models are the main means to evaluate ecological efficiency. The index system used the weight of selected indicators to analyze the interactions between the economy and the environment (Van Caneghem et al., 2010). Although the social, economic and environmental factors can be considered in the index, some problems still remain including unreasonable and subjective factors (Martinez-Alier et al., 1998), which can be compensated for through the use of models. The Data Envelopment Analysis (DEA) model is widely used in eco-efficiency analysis because it uses the same inputs and output types as multiple indicators to evaluate the relative effectiveness of decision-making units. However, by automatically reducing the environmental weighting of subjective factors, the DEA method clearly shows the combination of multiple inputs and outputs (Li et al., 2007; Qiu and Zhu, 2007; Wursthorn et al., 2011). The current studies on the application of ecological efficiency mainly focused on the competitive advantage of the region in long-term development through ecological efficiency on a regional scale (Hur et al., 2004; Seppäläa et al., 2005; Zhang et al., 2008; Van Caneghem et al., 2010; Wursthorn et al., 2011).

As one of the largest natural grassland region around the world, Hunlunbuir has rich grassland resources and herbage species, forming an important ecological barrier in northern China, but it faces the problems of grassland degradation and declining in ecological service function (Shan et al., 2011; Reiche et al., 2012). The government implemented series of ecological protection and construction projects, such as ‘Returning Grazing Land to Grassland’, ‘Returning Farmland to Forest’ and ‘Forage-Livestock Balance’. Nonetheless, the effects of these policies especially in the ecological aspect are not clear. Recently, with the change of government function and the construction of government service requirements, policy assessment, especially third-party policy evaluation, has been increasingly applied by researchers and governmental departments in China? (Adelle and Weiland, 2012). Third-party assessment is a necessary and effective external check to improve government performance and management and avoids the concerns of the traditional self-evaluation system by government (Heil et al., 2013). Yet, opinions vary on the definition of “third-party", and often a third party is generally independent of the policy makers and practitioners of the policy that is being evaluated. The foundation of a fair and reasonable assessment is independence, professionalism and authority. The Difference-in-Difference (DiD) approach is widely used in third-party assessment (Wang et al., 2018). This method clarifies the effects of policy interventions in empirical research (Athey and Imbens, 2006). The prerequisite for the method is that policy changes have not affected every sample or the whole study area at the same time, so that we can separate the treated group and control group (Dimick and Ryan, 2014).

In this context, we measured the ecological efficiency for each county in Hulunbuir during 2001–2015 using a Super-efficiency DEA method, and then applied the DiD approach to analyze the effect of the policy on ecological efficiency, choosing ‘Forage-Livestock Balance’, which is one of the most important policies for grassland management, as study object to refine the policy options for improving the efficiency of grassland resource usage, alleviating the pressure on the grassland ecology, improving the ability tackling climate change and providing suggestions on the sustainable development of grassland regions.

In the rest of this paper, methods and data sources are described in Section 2. The results on the ecological efficiency and the effect of the policy 'Forage-Livestock Balance' are reported in Section 3. Finally, the conclusions and policy implications are discussed in Section 4.

## 2. Data and methods

### 2.1. Indicators and data

Assessing ecological efficiency requires indicators of both economic and environmental performances (Thanawong et al., 2014). The essence of ecological efficiency is to maximize economic output by minimizing resource consumption and environmental pollution. Therefore, in a practical application, the profitability index is usually used as the output index, and the cost index is treated as input index, generally from aspects of capital, labor and land that related to livestock husbandry. So, fixed asset investment of first industry is selected as capital indicator, first industry working population is selected as labor indicator, Net Primary Productivity (NPP) of grassland vegetation is selected as the land indicator because grassland resources is the main consumption in the process of developing livestock husbandry, and added value of livestock husbandry is selected as output index to construct an index system for ecological efficiency evaluation (Table 1). All the data in this study came from the Inner Mongolia Statistical Yearbooks (2000–2015) and the Hulunbuir Statistical Yearbooks (2000–2015), the NPP was calculated through GLOPEM model based on the Landsat TM/ETM Remote Sensing Image Data from 2000 to 2015 provided by Chinese Academy of Sciences Resource and Environmental Science Data Center.

### 2.2. Methods

#### 2.2.1. Super-efficiency Data Envelopment Analysis

The Super-efficiency DEA method was proposed by Andersen and Petersen (1993). When evaluating the ecological efficiency of the decision units with Super-efficiency DEA, the specific decision unit is excluded. While in the calculation process an ineffective decision unit is kept unchanged because of its production frontier, so the efficiency value is the same as that of a traditional DEA model. However, for effective decision-making units, the input is increased in proportion to the unchanged efficiency value, and the ratio of the increase is recorded as the value of the super efficiency evaluation. Therefore, the efficiency value calculated is greater than that of a traditional DEA model because of the backward movement of the frontier surface. The Super-efficiency DEA solves the problem that the traditional DEA model cannot evaluate when multiple evaluation units are on the frontier of production. We selected panel data from 2000 to 2015 to calculate the ecological efficiency of Hulunbuir. The model structure was as follows.

$$\begin{aligned} &\min\left[\theta-\varepsilon\left(\sum_{i=1}^{m}S_i^- + \sum_{r=1}^{s}S_r^+\right)\right] \\ &s.t.\sum_{\substack{j=1\\ j\neq k}}^{n}\lambda jxij + S_i^- = \theta x0, i = 1,2,\cdots,m \\ &\sum_{\substack{j=1\\ j\neq k}}^{n}\lambda jyrj - S_r^+ = y0, r = 1,2,\cdots,s \\ &\lambda j \geq 0, j = 1,2,\cdots,n, S_r^+ \geq 0, S_i^- \geq 0 \end{aligned} \quad (1)$$

where, $\theta$ is the super efficiency of the decision unit; $\varepsilon$ is infinitely small for non-Archimedes geometry; $m$, $s$, $n$,respectively, represent the input variable dimension, the output variable dimension and the region quantity; $S_i^-, S_r^+$ is the relaxation variable; $xij, yij$ are input variables and output variables; and $\lambda$ is the weight coefficient. When $\theta$<1, the decision unit does not achieve optimal efficiency, while $\theta$>1 shows a more optimal measure.

#### 2.2.2. The difference-in-difference approach

The DiD approach can be used to clarify the impact of policy on ecological efficiency. It is very prevalent in socio-economic empirical research (Athey and Imbens, 2006; Hu et al., 2017), as well as in experimental physical sciences (Wang et al., 2018). The research design must meet three basic hypotheses: i) the macro environment for the treatment group and control group should be identical; ii) the intervention should only affect the treatment group and do nothing to control group; and iii) the critical component should not change over time. The estimates are derived from regression models rather than simple subtraction. Using a regression model allows the estimates to be controlled by other related factors that may vary in groups. The regression model also provides a statistical quantification that can verify the significance of the policy effect (Dimick and Ryan, 2014).

In this study, we firstly used a Least Angle Regression (LARS) model to implement the Least Absolute Shrinkage and Selectionator operator (LASSO), the Cp value is declining with the variables being added into model (Table 2). Based on the least Cp value, we select policy, precipitation, firstpopratio, D, D_policy, sun and temperature as the explanatory variables in the regression model. A

**Table 2**
Results of LARS test.

| Cp | R-square | Action |
|---|---|---|
| 205.5574 | 0.0000 | |
| 69.3359 | 0.4083 | +Policy |
| 37.6547 | 0.5078 | +Precipitation |
| 33.2197 | 0.5268 | +Firstpopratio |
| 22.1712 | 0.5653 | +D |
| 19.0055 | 0.5806 | +Firstratio |
| 13.8485 | 0.6017 | +D_policy |
| 14.8471 | 0.6047 | +Sun |
| 9.0000 | 0.6278 | +Temperature |

**Table 1**
The evaluation system of grassland ecological efficiency in Hulunbuir.

| Category | Constitute | Specific indicators | Obs | Mean | Std.Dev | Min | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| Output | Livestock value | Added value of livestock husbandry | 135 | 85939 | 83413 | 2117 | 515213 | $10^4$ yuan |
| Input | Capital | Fixed asset investment | 135 | 3056215 | 3507633 | 176196 | 11200000 | $10^4$ yuan |
| | Labor | First industry working | 135 | 42793 | 45808 | 691 | 139632 | human |
| | Land(Grassland) | NPP | 135 | 233.46 | 78.96 | 87.58 | 449.93 | gC/ ( $m^2$a ) |

**Table 3**
Statistical summaries of all variables.

| Variable | Obs | Mean | Std.Dev. | Min | Max | Unit |
|---|---|---|---|---|---|---|
| T | 135 | 0.400 | 0.492 | 0 | 1 | – |
| D | 135 | 0.444 | 0.499 | 0 | 1 | – |
| T*D | 135 | 0.178 | 0.384 | 0 | 1 | – |
| Firstratio | 135 | 26.60 | 17.08 | 2.90 | 67.40 | % |
| Firstpoprā o | 135 | 48.88 | 21.94 | 4.30 | 82.20 | % |
| Temperature | 135 | 5.52 | 13.88 | −22.27 | 37.92 | 0.1 °C |
| Precipitation | 135 | 370.09 | 139.44 | 78.00 | 758.10 | 0.1 mm |
| Sun | 135 | 2673.90 | 235.86 | 2060.00 | 3227.00 | 0.1 h |

summary statistics of variables are presented in Table 3.

Then, we implemented a Variance Inflation Factor (VIF) test for all selected variables in order to check the multicollinearity (Table 4). The result shows that the VIF value of all selected variables is less than 10. There is no obvious multicollinearity among the variables.

Hulunbuir can generally be divided into two regions based on the characters of livestock husbandry, one is pastoral area, where livestock husbandry is the pillar industry; and the other is semi-agricultural and semi-pastoral area and agriculture area, where livestock husbandry is not the pillar industry. In this paper, we regarded pastoral area as traditional category, and semi-agricultural and semi-pastoral area and agriculture area as non-traditional category. Efficiency values have relative consistency in the two regions perspective. In this sense, we conducted an experimental research with observational data, to clarify the effect of policy implementation on livestock efficiency through investigating pre-policy and post-policy differences in livestock efficiency of traditional pastoral areas and non-traditional pastoral areas. We set up whether it is the traditional pasture area or not as $D \in \{1, 0\}$. The traditional pastoral area included Chen, Xinzuo, Xinyou and Ewenki counties, with the rest of the counties as the non-traditional pasture area. The time period were divided into before and after 2010, where Period one ($Tpost \in 1$) relates to the time after policy implementation (after 2010) and Period zero ($Tpost \in 0$) relates to the time before policy implementation (before 2010). To ensure the macro environment remained the same in the treatment and control groups, we incorporated extra control variables into the model. Among these control variables, the proportion of agricultural population to total population represented the labor input factor and the proportion of the added value of the main industry to GDP reflected the regional industry structure, which can affect the grass-based ecological efficiency. Average temperature, precipitation and sunshine duration were used to control the physical environment. The model is shown as:

$$Yit = \beta 0 + \beta 1Tit + \beta 2Dit + \beta 3Tit{*}Dit + \beta 4X1it + \beta 5X2it + \beta 6X3it + \beta 7X4it + \beta 8X5it + \varepsilon it$$

where $Y$ represents grass-based ecological efficiency, $T$ is a time dummy variable to be divide time into two periods (before and after 2010). $D$ shows whether the region was a traditional pasture area or not. $X_1$–$X_5$ respectively represent the proportion of agricultural population to total population, the proportion of the added value of the main industry to GDP, average temperature, precipitation and sunshine duration. $\varepsilon$ captures the residual error of the model. $\beta$ represents coefficients estimated by the model. The effects of policy on grass-based ecological efficiency during 2001–2015 for traditional pasture and non-traditional pasture can be extracted as shown in Table 5.

**Table 4**
Multicollinearity test results.

| Variable | VIF | 1/VIF |
|---|---|---|
| D | 3.03 | 0.3302 |
| Policy | 2.64 | 0.3785 |
| D_policy | 2.64 | 0.3793 |
| Precipitation | 2.15 | 0.4659 |
| Sun | 2.07 | 0.4835 |
| Firstratio | 1.60 | 0.6244 |
| Temperature | 1.52 | 0.6564 |
| Firstpopratio | 1.33 | 0.7531 |
| Mean VIF | 2.12 | |

## 3. Results and discussions

### 3.1. Ecological efficiency of livestock husbandry

The results showed that there were spatial differences in the ecological efficiency of grass and livestock husbandry in Hulunbuir (Table 6). In 2001, the ecological efficiency levels among all counties were quite low, with the highest value in Xinyou County (0.57) and the lowest in Mo County (just 0.09). In 2015, the efficiency level had been greatly improved, with the highest absolute value in Yakeshi County (1.59) and the lowest value in Chen County (0.57), and the efficiency value in Yakeshi County had increased the most, from 0.14 in 2001 to 1.59 in 2015.

### 3.2. Effects of policy implementation on ecological efficiency

We estimated the impact of policy on ecological efficiency using the DiD approach. As shown in Fig. 1, we presented the ecological efficiency of traditional and non-traditional categories. Although the ecological efficiency dropped in some years in both traditional and non-traditional pastoral regions during 2001–2015, it overall showed an increasing trend. Prior to policy implementation (before 2010), there was no obvious difference in ecological efficiency between traditional and non-traditional pastoral regions. The average value of ecological efficiency in two regions was 0.339 and 0.385, respectively, during 2001–2009. After policy implementation, the average value of grass-based ecological efficiency in non-traditional pasture areas grew to 0.915, which was much higher than that of traditional pasture areas, with an average of 0.659 during 2010–2015.

The results of the DiD model in Table 7 suggest the proportion of agricultural added value ($X_1$) and labor ($X_2$) tended to depress ecological efficiency. Every 1% change of $X_1$ and $X_2$ decreased the efficiency index value by 0.003 and 0.002, respectively. For natural factors, precipitation positively affected efficiency, increasing the efficiency index value by $3.28{*}10^{-4}$ with 1 mm precipitation.

The results showed that the policies have a significant impact on ecological efficiency. Among the policies implemented by governments, 'Forage-Livestock Balance' is the earliest policy paying attention to livestock husbandry development, which is the main income of residents especially in the pastoral areas. The backward development mode and single industrial structure are major reasons that lead to a low ecological efficiency in traditional pasture areas compared to non-traditional pastoral areas, and quite a low level of education is an important constraints to livestock husbandry development in traditional pasture areas.

Furthermore, from the Table 7, climate change variables including temperature, precipitation and sunshine also have an important impact on ecological efficiency, among which, precipitation is the most crucial factor. Recently, extreme disasters caused by climate change lead to a quite fragile socio-economic system in

**Table 5**
Effect of policy on ecological efficiency.

| Treated | Before policy implementation (T = 0) | After policy implementation (T = 1) | Difference |
|---|---|---|---|
| Traditional pasture (D = 1) | $\beta 0 + \beta 2 + \sum_{i=4}^{8} \beta i$ | $\beta 0 + \beta 1 + \beta 2 + \beta 3 + \sum_{i=4}^{8} \beta i$ | $\beta 1 + \beta 3$ |
| Non-traditional pasture (D = 0) | $\beta 0 + \sum_{i=4}^{8} \beta i$ | $\beta 0 + \beta 1 + \sum_{i=4}^{8} \beta i$ | $\beta 1$ |
| Difference | $\beta 2$ | $\beta 2 + \beta 3$ | $\beta 3$ |

**Table 6**
Levels of ecological efficiency of livestock husbandry among all counties in Hulunbuir in 2001–2015.

| County | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| Arong | 0.20 | 0.12 | 0.14 | 0.32 | 0.34 | 0.40 | 0.61 | 0.58 |
| Chen | 0.18 | 0.18 | 0.22 | 0.32 | 0.37 | 0.31 | 0.34 | 0.36 |
| Ewenke | 0.22 | 0.15 | 0.32 | 0.31 | 0.36 | 0.31 | 0.32 | 0.37 |
| Hailaer | 0.14 | 0.10 | 0.22 | 0.30 | 0.41 | 0.43 | 0.36 | 0.55 |
| Mo | 0.09 | 0.11 | 0.11 | 0.18 | 0.25 | 0.40 | 0.43 | 0.40 |
| Xinyou | 0.57 | 0.34 | 0.36 | 0.52 | 0.40 | 0.30 | 0.33 | 0.38 |
| Xinzuo | 0.24 | 0.24 | 0.18 | 0.24 | 0.42 | 0.37 | 0.40 | 0.47 |
| Yakeshi | 0.14 | 0.17 | 0.19 | 0.33 | 0.58 | 0.55 | 0.66 | 1.02 |
| Zhalantun | 0.56 | 0.40 | 0.56 | 0.46 | 0.48 | 0.65 | 0.76 | 0.76 |
| County | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | Average |
| Arong | 0.49 | 0.83 | 0.60 | 1.10 | 0.93 | 0.72 | 0.84 | 0.57 |
| Chen | 0.39 | 0.45 | 0.57 | 0.59 | 0.59 | 0.63 | 0.57 | 0.42 |
| Ewenke | 0.40 | 0.47 | 0.55 | 1.33 | 0.84 | 0.82 | 0.79 | 0.51 |
| Hailaer | 0.58 | 0.60 | 0.79 | 0.86 | 1.11 | 0.92 | 0.96 | 0.58 |
| Mo | 0.35 | 0.50 | 0.60 | 0.75 | 1.06 | 1.47 | 0.90 | 0.53 |
| Xinyou | 0.38 | 0.42 | 0.56 | 0.60 | 0.64 | 0.67 | 0.67 | 0.46 |
| Xinzuo | 0.49 | 0.58 | 0.65 | 0.59 | 0.84 | 0.89 | 0.89 | 0.51 |
| Yakeshi | 0.87 | 0.86 | 1.06 | 0.97 | 0.95 | 0.87 | 1.59 | 0.78 |
| Zhalantun | 0.66 | 0.91 | 0.75 | 0.86 | 0.83 | 1.12 | 0.89 | 0.72 |

pastoral area. Raising the capacity to deal with the extreme meteorological disasters caused by climate change is a problem that must be solved to achieve the sustainable development of livestock husbandry in pastoral areas.

## 4. Conclusions and policy implications

In this study, we apply a Super-efficiency DEA model to measure the ecological efficiency of livestock husbandry in each county in Hulunbuir during 2001–2015, then we used DiD approach to analyze the effect of the 'Forage-Livestock Balance' policy on ecological efficiency of livestock husbandry in Hulunbuir. The results provide useful information for the sustainable development in grassland regions in China.

Compared with traditional pasture, non-traditional pasture showed greater improvement in ecological efficiency during 2001–2015, indicating that although traditional grazing is resilient and adaptable to natural conditions, with continuous development of livestock husbandry, especially in the context of increasingly grassland over-grazing, serious degradation of grassland vegetation and climate change, traditional grazing management cannot ensure coordinated and stable development between grassland ecological function and livestock production. There must be an improvement in the ecological efficiency of livestock husbandry in grassland regions through technological advances and large-scale production.

Policy is a crucial factor for achieving sustainable development in grassland areas. Since year 2000, in order to control grassland degradation, most polices paid attention to protect grassland

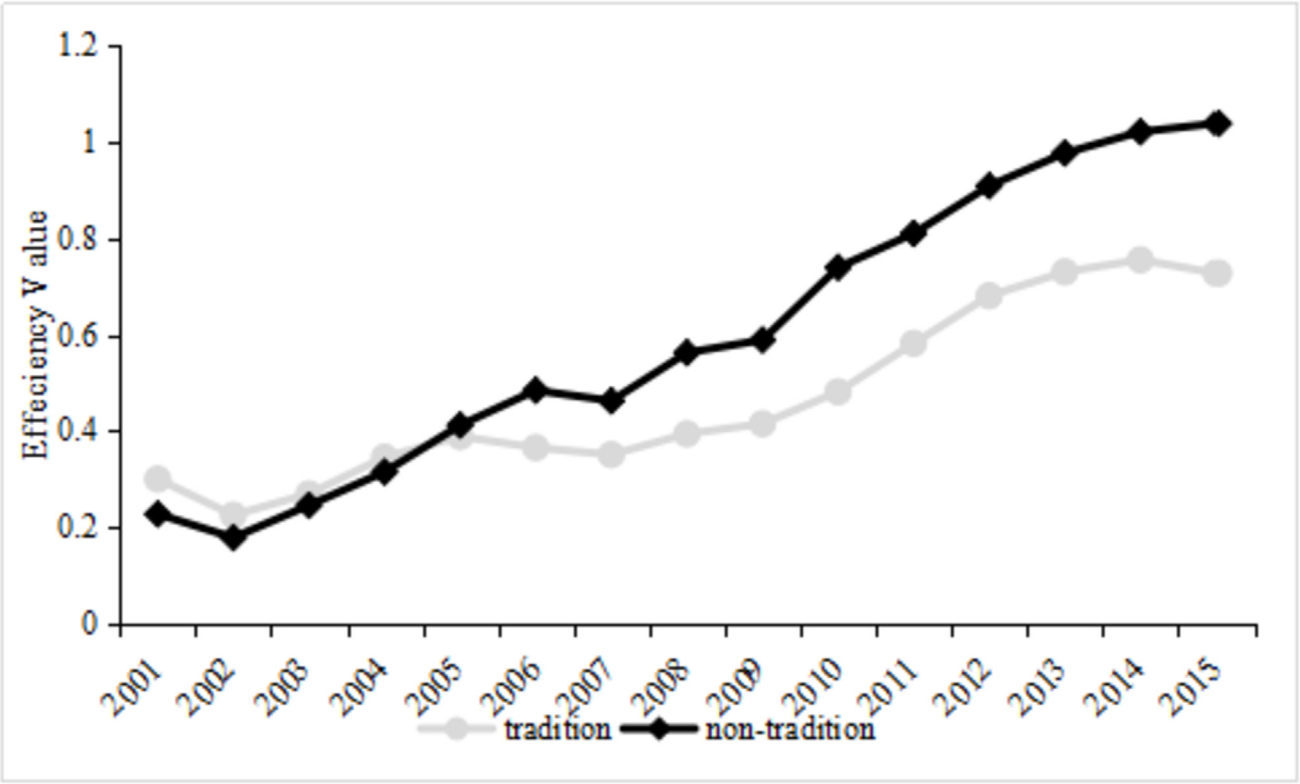


**Fig. 1.** Grass-based ecological efficiency in traditional and non-traditional pastures in 2001–2015.

**Table 7**
Difference in difference (DiD) model results.

| Efficiency | Coefficients | Std.error | Z value | P value |
|---|---|---|---|---|
| Pre- and post- event (T ) | $0.427^{***}$ | 0.053 | 8.03 | 0.000 |
| Traditional and non-traditional pasturing area ( D ) | −0.051 | 0.063 | −0.80 | 0.423 |
| Interaction term ( T*D ) | $-0.149^{**}$ | 0.067 | −2.22 | 0.027 |
| Proportion of agricultural added value in total GDP ( $X_1$ ) | $-0.003^{**}$ | 0.001 | −2.06 | 0.040 |
| Proportion of agricultural labors in total labors ($X_2$ ) | $-0.002^{*}$ | 0.001 | −1.81 | 0.070 |
| Average temperature ( $X_3$ ) | 0.002 | 0.002 | 1.01 | 0.310 |
| Precipitation ( $X_4$ ) | $3.28 \times 10^{-4*}$ | $1.73 \times 10^{-4}$ | 1.89 | 0.059 |
| Sunshine duration ( $X_5$ ) | $1.18 \times 10^{-4}$ | $9.93 \times 10^{-5}$ | 1.19 | 0.234 |
| Constant | 0.146 | 0.292 | 0.50 | 0.617 |
| $R^2$ | 0.627 | | | |
| Wald chi 2 | $207.84^{***}$ | | | |

NOTE : *P < 0.1, **P < 0.05, ***P < 0.01.

ecological function and have achieved remarkable results with overall increase of ecological efficiency among counties in Hulunbuir. However, there should be a balance between ecological conservation and livestock production. In the future, policy implementation should focus on how to improve livestock industry development as well as on the conservation of grasslands so as to achieve sustainable development.

Effective grassland management to cope with climate change is also an important measure to improve the efficiency of livestock husbandry, alleviating pressure on grassland ecology and ensuring people's living quality in the context of climate change and recurrent disaster risks. Disaster emergency defense strategies must be strengthened in the face of more frequent grassland disasters, including better infrastructure construction for disaster prevention and resilience, improvements to the prediction of natural disasters, and establishment of a system of disaster warning and emergency response, to minimize the damage to grassland havitats and the livestock husbandry economy caused by major meteorological disasters. Livestock production should take advantage of favorable climatic conditions when they fit.

The limitation of this paper is that, we applied the DiD approach to analyze the effect of the policy on ecological efficiency through single policy, but the changes of grassland ecological efficiency are the results of multiple policies, subsequent research may focus on the intrinsic links between grassland management policies and the coupling effects on ecological efficiency.

## Conflicts of interest

The authors declare no conflict of interests.

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